Exhibit 2

<table>
<tr><th>US6671307</th><th>Trane's Wireless Comm Interface ("Accused Product")</th></tr>
<tr><td>4. A spread-spectrum method improvement for sending data over a communications channel, comprising the steps of:</td><td>

The accused product practices an improved spread-spectrum method for sending data over a communications channel (e.g., Wireless channel).

http://web.archive.org/web/20141228055948/http://www.trane.com/commercial/north-america/us/en/controls/HVAC-equipment-controls/wireless-communications.html

</td></tr>
</table>

TRANE

Product Data Sheet

Wireless Comm Interface (WCI)
Part Number: X13790901010

Trane Wireless Comm replaces the BACnet communication link and sensor wire on Tracer™ building automation systems for faster, easier, lower-risk installation and life-cycle savings.

http://web.archive.org/web/20150926075141/http://www.trane.com/content/dam/Trane/Commercial/global/controls/wireless/documents/BAS-PRC039-EN_04162013.pdf

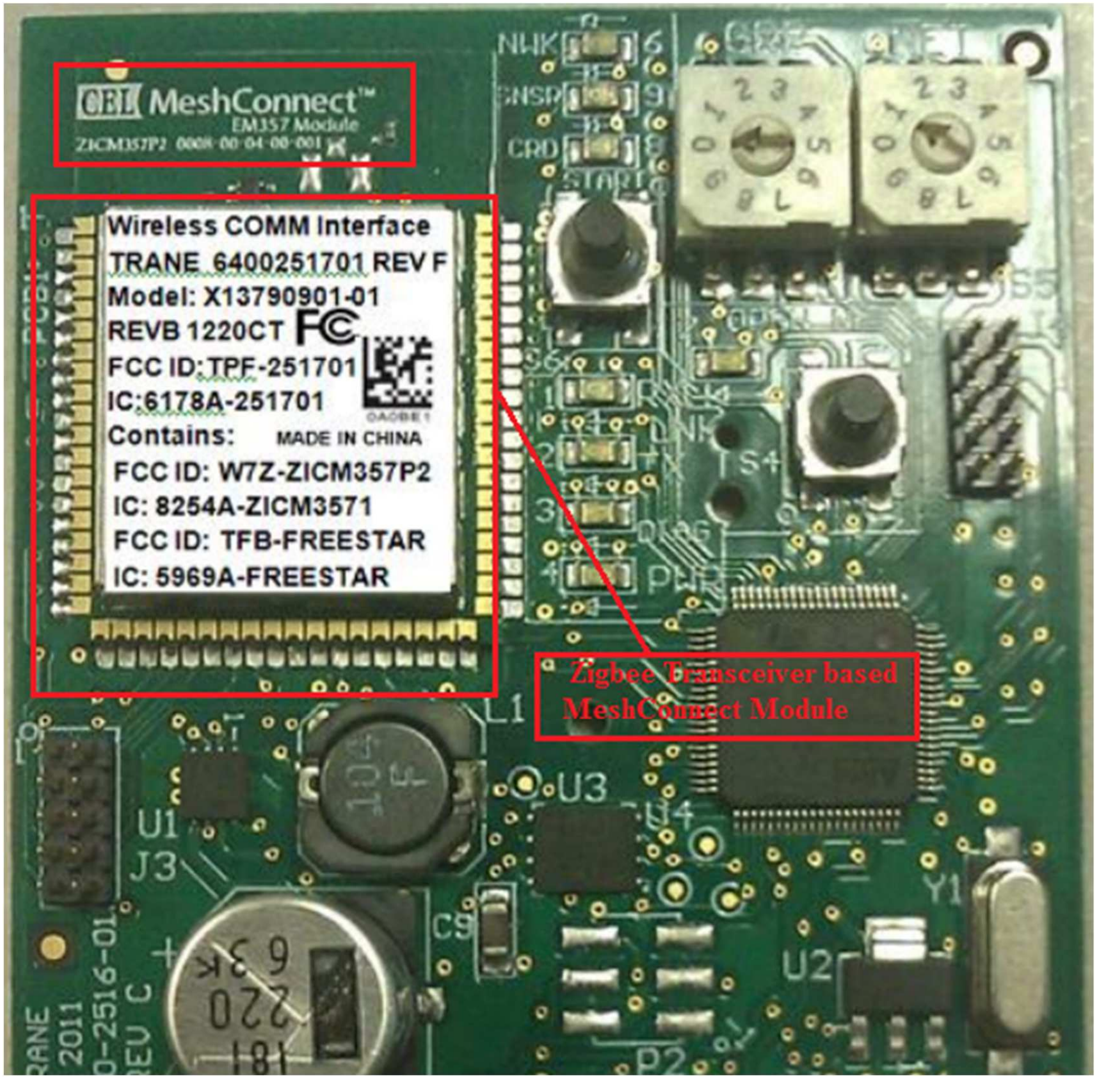
	Trane technology helps prepare your facilities for the future of building information. Wireless Comm runs BACnet® protocol over ZigBee® Building Automation standards. Trane Wireless Comm is the 1st HVAC manufacturer to be Zigbee Certified. Adherence to Zigbee Building Automation, the global wireless standard for interoperable products, enables secure and reliable wireless monitoring and control over commercial building systems. Wireless Comm also conforms to the IEEE 802.15.4 standard, which ensures that your wireless BAS Communication system will reliably coexist with other wireless systems, including Bluetooth® and Wi-Fi™. http://web.archive.org/web/20141228055948/http://www.trane.com/commercial/north-america/us/en/controls/HVAC-equipment-controls/wireless-communications.html#tabs-1

Specifications and Agency Compliance

Specifications	
Operating temperature	-40 to 158ºF (-40 to 70ºC)
Storage temperature	-40 to 185ºF (-40 to 85ºC)
Storage and operating humidity range	5% to 95% relative humidity (RH), non-condensing
Voltage	24 Vac/Vdc nominal ± 10% If using 24 Vac, polarity must be maintained.
Receiver power consumption	<2.5 VA
Housing material	Polycarbonate/ABS (suitable for plenum mounting), UV protected, UL 94: 5 VA flammability rating
Mounting	3.2 in (83 mm) with 2 supplied mounting screws
Range[a]	Open range: 2,500 ft (762 m) with packet error rate of 2%. Indoor: Typical range is 200 ft (61 mm); actual range is dependent on the environment. See BAS-SVX55 for more detail.
Output power	North America: 100 mW
Radio frequency	2.4 GHz (IEEE Std 802.15.4-2003 compliant) (2405–2480 MHz, 5 MHz spacing)
Radio channels	16

http://web.archive.org/web/20150926075141/http://www.trane.com/content/dam/Trane/Commercial/global/controls/wireless/documents/BAS-PRC039-EN_04162013.pdf

As shown below, the accused product contains ZICM357SP2 MeshConnect module which is based on 2.4 GHz ZigBee Transceiver (EMBER's 357 ZigBee Radio).



DATASHEET

CEL MeshConnect™

MeshConnect™ EM357 Mini Modules

ZICM357SP0, ZICM357SP2

Ember™ EM357 Transceiver Based Modules

Integrated Transceiver Modules for ZigBee / IEEE 802.15.4
Development Kit available: ZICM-EM35X-DEV-KIT-2

DESCRIPTION

The MeshConnect™ EM357 Mini Modules from California Eastern Laboratories (CEL) combine high performance RF solutions with the market's premier ZigBee® stack. Available in low and high output power options (+8dBm and +20dBm), these modules can accommodate variable range and performance requirements. The mini module footprint makes them suitable for a wide range of ZigBee applications. The MeshConnect EM357 Mini Modules are certified and qualified, enabling customers to accelerate time to market by greatly reducing the design and certification phases of development.

CEL's MeshConnect EM357 Mini Modules (ZICM357SP0 and ZICM357SP2) are based on the Ember EM357 ZigBee compliant SoC radio IC. The IC is a single-chip solution, compliant with ZigBee specifications and IEEE 802.15.4, a complete wireless solution for all ZigBee applications. The

CEL MeshConnect™ EM357 Mini Modules

- 192 kB FLASH
- 12 kB SRAM
- 32-bit ARM® Cortex™-M3
- Up to 23 GPIO Pins
- SPI (Master/Slave), TWI, UART
- Timers, Serial Wire/JTAG Interface
- 5-channel 14-bit ADC

	ZICM357SP0	ZICM357SP2
Tx:	+8dBm	+20dBm
Rx:	-100dBm	-103dBm
Link Budget:	+108dB	+123dB

FEATURES

- **High RF Performance:**
  Up to 123dB RF Link Budget
  RX Sensitivity:
  -100dBm (ZICM357SP0)
  -103dBm (ZICM357SP2)
- **Data Rate: 250kbps**
- **Advanced Cortex-M3 Processor**
- **Mini Footprint:**
  - 0.940" x 0.655"
  (23.9mm x 16.6mm)
- **Antenna Options**
  1) Integrated PCB Trace Antenna
  or
  2) RF Port for External Antenna

http://www.cel.com/pdf/datasheets/MeshConnect_EM357_Mini_Modules_DS.pdf

	 As depicted below, ZigBee standard is built on top of IEEE 802.15.4. Also presented below is the specifications of EMBER's 357 ZigBee SOC.

SILICON LABS

EM351/EM357

High-Performance, Integrated ZigBee/802.15.4 System-on-Chip

Features

- 32-bit ARM® Cortex -M3 processor
- 2.4 GHz IEEE 802.15.4-2003 transceiver & lower MAC
- 128 or 192 kB flash, with optional read protection
- 12 kB RAM memory
- AES128 encryption accelerator
- Flexible ADC, UART/SPI/TWI serial communications, and general purpose timers
- 24 highly configurable GPIOs with Schmitt trigger inputs

Industry-leading ARM® Cortex -M3 processor

- Leading 32-bit processing performance
- Highly efficient Thumb-2 instruction set
- Operation at 6, 12, or 24 MHz
- Flexible Nested Vectored Interrupt Controller

Low power consumption, advanced management

- RX Current (w/ CPU): 26 mA
- TX Current (w/ CPU, +3 dBm TX): 31 mA
- Low deep sleep current, with retained RAM and GPIO: 400 nA without/800 nA with sleep timer
- Low-frequency internal RC oscillator for low-power sleep timing
- High-frequency internal RC oscillator for fast (110 µs) processor start-up from sleep

Exceptional RF Performance

- Normal mode link budget up to 103 dB; configurable up to 110 dB
- –100 dBm normal RX sensitivity; configurable to –102 dBm (1% PER, 20 byte packet)
- +3 dB normal mode output power; configurable up to +8 dBm
- Robust Wi-Fi and Bluetooth coexistence

Innovative network and processor debug

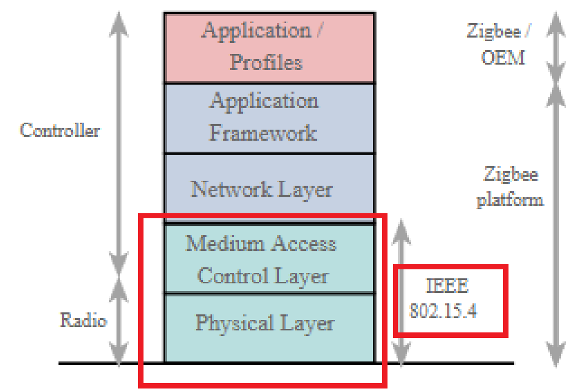
- Packet Trace Port for non-intrusive packet trace with Ember development tools
- Serial Wire/JTAG interface
- Standard ARM debug capabilities: Flash Patch & Break-point; Data Watchpoint & Trace; Instrumentation Trace Macrocell

Application Flexibility

- Single voltage operation: 2.1–3.6 V with internal 1.8 and 1.25 V regulators
- Optional 32.768 kHz crystal for higher timer accuracy
- Low external component count with single 24 MHz crystal
- Support for external power amplifier
- Small 7x7 mm 48-pin QFN package

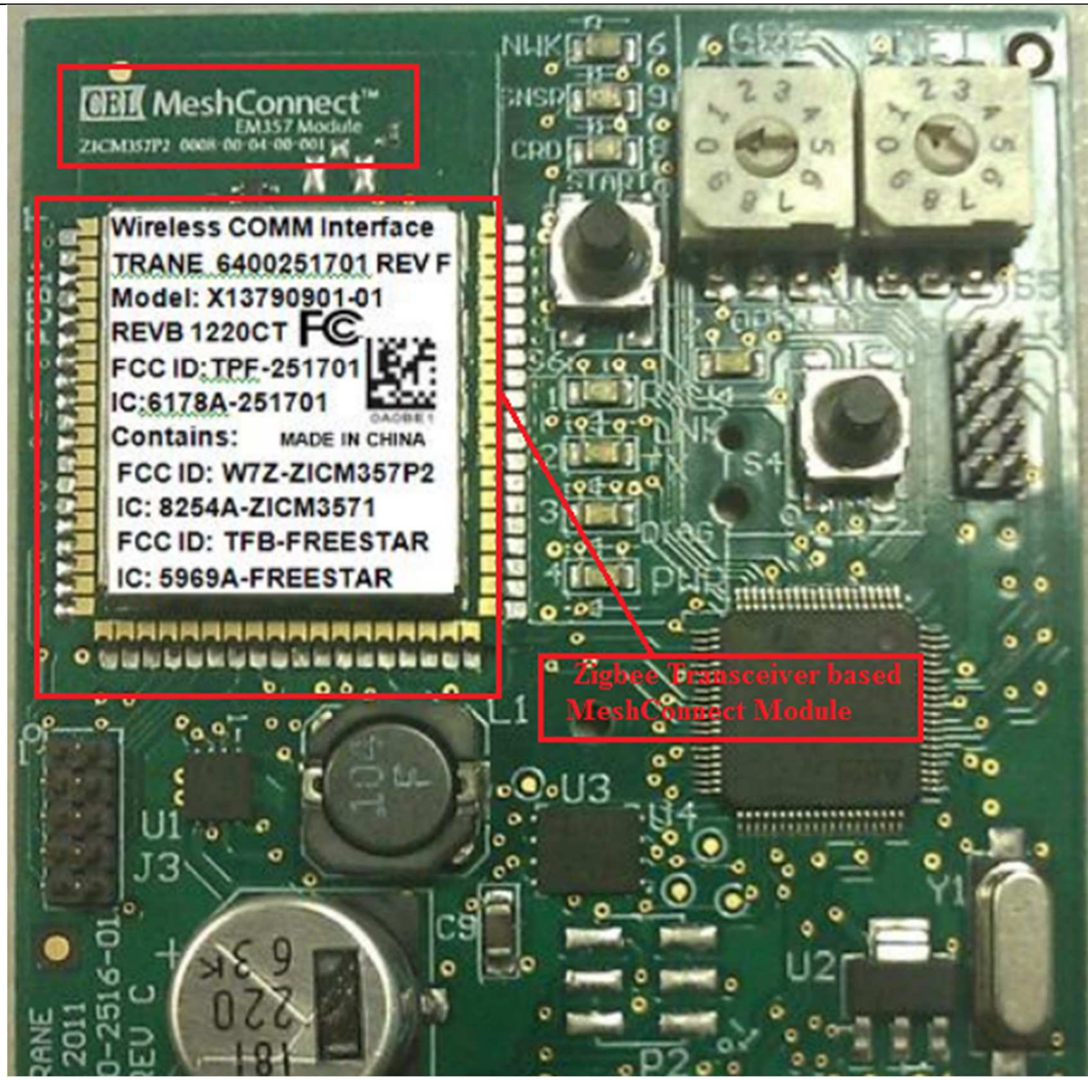
https://www.silabs.com/documents/public/data-sheets/EM35x.pdf

	What is ZigBee Technology *Zigbee has been established for many years as an IoT network standard for remote control and sensing applications.* **Zigbee Includes:** Zigbee technology basics The Zigbee standard is a standard built on top of IEEE 802.15.4 which provides the upper layers for control and sensor applications. It has been designed to be very robust so that it can operate reliably in harsh radio environments, providing security and flexibility. As an open standard, Zigbee is able to operate using items from a variety of manufacturers. https://www.electronics-notes.com/articles/connectivity/zigbee/what-is-zigbee-technology-tutorial.php

	ZigBee basics The distances that can be achieved transmitting from one station to the next extend up to about 70 metres, although very much greater distances may be reached by relaying data from one node to the next in a network.  The differnet ISO layers in a Zigbee protocol stack https://www.electronics-notes.com/articles/connectivity/zigbee/what-is-zigbee-technology-tutorial.php Zigbee products use very low power and are available at very low cost. They are based on LR-WPAN (low rate wireless personal area network) standard i.e. IEEE 802.15.4. Zigbee products will have protocol layers (PHY,MAC,network,security,application). Network,security and application layers are defined by zigbee alliance. http://www.rfwireless-world.com/Terminology/what-is-zigbee.html

	As shown below, ZigBee is a DSSS based technology. DSSS, also referred to as "Direct Sequence Spread Spectrum", is a type of spread spectrum technology. **Physical and MAC layers** The system is specified to operate in one of the three license free bands at 2.4 GHz, 915 MHz for North America and 868 MHz for Europe. In this way the standard is able to operate around the globe, although the exact specifications for each of the bands are slightly different. At 2.4 GHz there are a total of sixteen different channels available, and the maximum data rate is 250 kbps. For 915 MHz there are ten channels and the standard supports a maximum data rate of 40 kbps, while at 868 MHz there is only one channel and this can support data transfer at up to 20 kbps. The modulation techniques also vary according to the band in use. Direct sequence spread spectrum (DSSS) is used in all cases. However for the 868 and 915 MHz bands the actual form of modulation is binary phase shift keying. For the 2.4 GHz band, offset quadrature phase shift keying (O-QPSK) is employed. In view of the fact that systems may operate in heavily congested environments, and in areas where levels of extraneous interference is high, the 802.15.4 specification has incorporated a variety of features to ensure exceedingly reliable operation. These include a quality assessment, receiver energy detection and clear channel assessment. CSMA (Carrier Sense Multiple Access) techniques are used to determine when to transmit, and in this way unnecessary clashes are avoided. https://www.electronics-notes.com/articles/connectivity/zigbee/what-is-zigbee-technology-tutorial.php The accused product operates in 2.4 GHz range.

	Zigbee Physical Layer(PHY) There are two **Physical layer** formats one each for 868/915MHz and 2450MHz bands in **Zigbee** standard. 868-868.6 MHz zigbee band delivers about 20Ksymbol/s with BPSK modulation employed. 902-928 MHz band delivers about 40 Ksymbol/s with BPSK modulation. 2400-2483.5 MHz delivers about 62.5 Ksymbol/s with O-QPSK modulation. http://www.rfwireless-world.com/Tutorials/Zigbee-physical-layer.html


CEL MeshConnect™
EM357 Module
Wireless COMM Interface
TRANE 6400251701 REV F
Model: X13790901-01
REVB 1220CT
FCC ID: TPF-251701
IC: 6178A-251701
Contains: MADE IN CHINA
FCC ID: W7Z-ZICM357P2
IC: 8254A-ZICM3571
FCC ID: TFB-FREESTAR
IC: 5969A-FREESTAR
Zigbee Transceiver based MeshConnect Module

DATASHEET

CEL MeshConnect™

MeshConnect™ EM357 Mini Modules

ZICM357SP0 ZICM357SP2

Ember™ EM357 Transceiver Based Modules

Integrated Transceiver Modules for ZigBee / IEEE 802.15.4
Development Kit available: ZICM-EM35X-DEV-KIT-2

DESCRIPTION

The MeshConnect™ EM357 Mini Modules from California Eastern Laboratories (CEL) combine high performance RF solutions with the market's premier ZigBee® stack. Available in low and high output power options (+8dBm and +20dBm), these modules can accommodate variable range and performance requirements. The mini module footprint makes them suitable for a wide range of ZigBee applications. The MeshConnect EM357 Mini Modules are certified and qualified, enabling customers to accelerate time to market by greatly reducing the design and certification phases of development.

CEL's MeshConnect EM357 Mini Modules (ZICM357SP0 and ZICM357SP2) are based on the Ember EM357 ZigBee compliant SoC radio IC. The IC is a single-chip solution, compliant with ZigBee specifications and IEEE 802.15.4, a complete wireless solution for all ZigBee applications. The

CEL MeshConnect™ EM357 Mini Modules

- 192 kB FLASH
- 12 kB SRAM
- 32-bit ARM® Cortex™-M3
- Up to 23 GPIO Pins
- SPI (Master/Slave), TWI, UART
- Timers, Serial Wire/JTAG Interface
- 5-channel 14-bit ADC

	ZICM357SP0	ZICM357SP2
Tx:	+8 dBm	+20 dBm
Rx:	-100 dBm	-103 dBm
Link Budget:	+108 dB	+123 dB

FEATURES

- **High RF Performance:**
  Up to 123dB RF Link Budget
  RX Sensitivity:
  -100dBm (ZICM357SP0)
  -103dBm (ZICM357SP2)
- **Data Rate: 250kbps**
- **Advanced Cortex-M3 Processor**
- **Mini Footprint:**
  - 0.940" x 0.655"
  (23.9mm x 16.6mm)
- **Antenna Options**
  1) Integrated PCB Trace Antenna
  or
  2) RF Port for External Antenna

http://www.cel.com/pdf/datasheets/MeshConnect_EM357_Mini_Modules_DS.pdf

Shown below are excerpts from 802.15.4 which defines physical layer of ZigBee standard. The modulation scheme employed by the accused product is O-QPSK since it operates in 2.4 GHz range. There are total 16 Channels (numbered from 11 to 26) in 2.4GHz operation.

WIRELESS MAC AND PHY SPECIFICATIONS FOR LR-WANS — IEEE Std 802.15.4-2003

6. PHY specification

This clause specifies two PHY options for IEEE 802.15.4. The PHY is responsible for the following tasks:

— Activation and deactivation of the radio transceiver
— ED within the current channel
— LQI for received packets
— CCA for CSMA-CA
— Channel frequency selection
— Data transmission and reception

Constants and attributes that are specified and maintained by the PHY are written in the text of this clause in italics. Constants have a general prefix of "a", e.g., *aMaxPHYPacketSize*, and are listed in Table 18. Attributes have a general prefix of "phy", e.g., *phyCurrentChannel*, and are listed in Table 19.

https://standards.ieee.org/standard/802_15_4-2003.html

IEEE Std 802.15.4-2003

This standard defines the protocol and interconnection of devices via radio communication in a personal area network (PAN). The standard uses carrier sense multiple access with a collision avoidance medium access mechanism and supports star as well as peer-to-peer topologies. The media access is contention based; however, using the optional superframe structure, time slots can be allocated by the PAN coordinator to devices with time critical data. Connectivity to higher performance networks is provided through a PAN coordinator.

This standard specifies two PHYs: an 868/915 MHz direct sequence spread spectrum (DSSS) PHY and a 2450 MHz DSSS PHY. The 2450 MHz PHY supports an over-the-air data rate of 250 kb/s, and the 868/915 MHz PHY supports over-the-air data rates of 20 kb/s and 40 kb/s. The PHY chosen depends on local regulations and user preference.

https://standards.ieee.org/standard/802_15_4-2003.html

6.1.1 Operating frequency range

A compliant device shall operate in one or several frequency bands using the modulation and spreading formats summarized in Table 1.

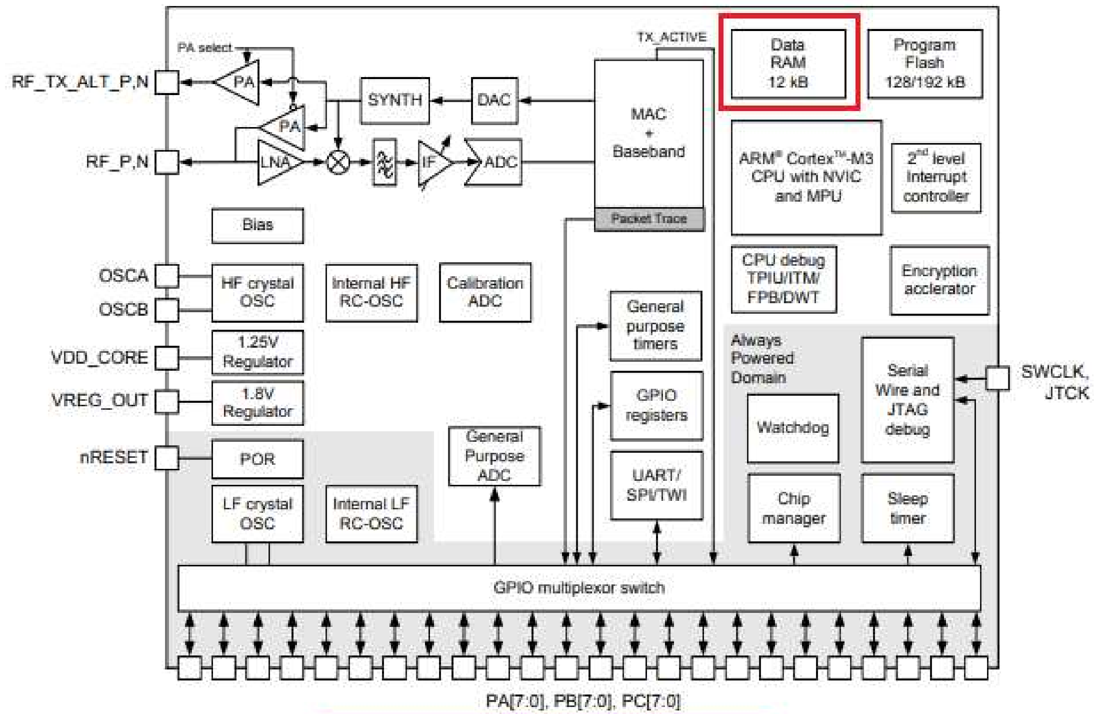
Table 1—Frequency bands and data rates

PHY (MHz)	Frequency band (MHz)	Spreading parameters		Data parameters		
		Chip rate (kchip/s)	Modulation	Bit rate (kb/s)	Symbol rate (ksymbol/s)	Symbols
868/915	868–868.6	300	BPSK	20	20	Binary
	902–928	600	BPSK	40	40	Binary
2450	2400–2483.5	2000	O-QPSK	250	62.5	16-ary Orthogonal

https://standards.ieee.org/standard/802_15_4-2003.html

	6.1.2 Channel assignments and numbering A total of 27 channels, numbered 0 to 26, are available across the three frequency bands. Sixteen channels are available in the 2450 MHz band, 10 in the 915 MHz band, and 1 in the 868 MHz band. The center frequency of these channels is defined as follows: $F_c = 868.3$ in megahertz, for $k = 0$ $F_c = 906 + 2\ (k - 1)$ in megahertz, for $k = 1, 2, ..., 10$ and $F_c = 2405 + 5\ (k - 11)$ in megahertz, for $k = 11, 12, ..., 26$ where k is the channel number. https://standards.ieee.org/standard/802_15_4-2003.html **6.5 2450 MHz PHY specifications** The requirements for the 2450 MHz PHY are specified in 6.5.1 through 6.5.3. **6.5.1 Data rate** The data rate of the IEEE 802.15.4 (2450 MHz) PHY shall be 250 kb/s. **6.5.2 Modulation and spreading** The 2450 MHz PHY employs a 16-ary quasi-orthogonal modulation technique. During each data symbol period, four information bits are used to select one of 16 nearly orthogonal pseudo-random noise (PN) sequences to be transmitted. The PN sequences for successive data symbols are concatenated, and the aggregate chip sequence is modulated onto the carrier using offset quadrature phase-shift keying (O-QPSK). https://standards.ieee.org/standard/802_15_4-2003.html

	Physical and MAC layers The system is specified to operate in one of the three license free bands at 2.4 GHz, 915 MHz for North America and 868 MHz for Europe. In this way the standard is able to operate around the globe, although the exact specifications for each of the bands are slightly different. At 2.4 GHz there are a total of sixteen different channels available, and the maximum data rate is 250 kbps. For 915 MHz there are ten channels and the standard supports a maximum data rate of 40 kbps, while at 868 MHz there is only one channel and this can support data transfer at up to 20 kbps. The modulation techniques also vary according to the band in use. Direct sequence spread spectrum (DSSS) is used in all cases. However for the 868 and 915 MHz bands the actual form of modulation is binary phase shift keying. For the 2.4 GHz band, offset quadrature phase shift keying (O-QPSK) is employed. In view of the fact that systems may operate in heavily congested environments, and in areas where levels of extraneous interference is high, the 802.15.4 specification has incorporated a variety of features to ensure exceedingly reliable operation. These include a quality assessment, receiver energy detection and clear channel assessment. CSMA (Carrier Sense Multiple Access) techniques are used to determine when to transmit, and in this way unnecessary clashes are avoided. https://www.electronics-notes.com/articles/connectivity/zigbee/what-is-zigbee-technology-tutorial.php
storing, at a transmitter, N bits of interleaved data as stored data, with N a number of bits in a symbol;	The spread-spectrum transmitter (e.g., ZigBee transceiver) utilized by the accused product practices storing, at a transmitter (e.g., data RAM of the ZigBee transceiver), N bits of interleaved data as stored data, with N (e.g., N=4) a number of bits in a symbol. As shown below, the spread-spectrum transmitter (e.g., ZigBee transceiver) utilized by the accused product maps 4 bits into on one data symbol and thereafter store it in a memory/buffer.

	Figure 3.1 shows a detailed block diagram of the EM35x.  **Figure 3.1. EM35x Block Diagram** https://www.silabs.com/documents/public/data-sheets/EM35x.pdf

SILICON LABS

EM351/EM357

High-Performance, Integrated ZigBee/802.15.4 System-on-Chip

Features

- 32-bit ARM® Cortex -M3 processor
- 2.4 GHz IEEE 802.15.4-2003 transceiver & lower MAC
- 128 or 192 kB flash, with optional read protection
- 12 kB RAM memory
- AES128 encryption accelerator
- Flexible ADC, UART/SPI/TWI serial communications, and general purpose timers
- 24 highly configurable GPIOs with Schmitt trigger inputs

Industry-leading ARM® Cortex -M3 processor

- Leading 32-bit processing performance
- Highly efficient Thumb-2 instruction set
- Operation at 6, 12, or 24 MHz
- Flexible Nested Vectored Interrupt Controller

Low power consumption, advanced management

- RX Current (w/ CPU): 26 mA
- TX Current (w/ CPU, +3 dBm TX): 31 mA
- Low deep sleep current, with retained RAM and GPIO: 400 nA without/800 nA with sleep timer
- Low-frequency internal RC oscillator for low-power sleep timing
- High-frequency internal RC oscillator for fast (110 µs) processor start-up from sleep

Exceptional RF Performance

- Normal mode link budget up to 103 dB; configurable up to 110 dB
- –100 dBm normal RX sensitivity; configurable to –102 dBm (1% PER, 20 byte packet)
- +3 dB normal mode output power; configurable up to +8 dBm
- Robust Wi-Fi and Bluetooth coexistence

Innovative network and processor debug

- Packet Trace Port for non-intrusive packet trace with Ember development tools
- Serial Wire/JTAG interface
- Standard ARM debug capabilities: Flash Patch & Break-point; Data Watchpoint & Trace; Instrumentation Trace Macrocell

Application Flexibility

- Single voltage operation: 2.1–3.6 V with internal 1.8 and 1.25 V regulators
- Optional 32.768 kHz crystal for higher timer accuracy
- Low external component count with single 24 MHz crystal
- Support for external power amplifier
- Small 7x7 mm 48-pin QFN package

https://www.silabs.com/documents/public/data-sheets/EM35x.pdf

6.5.2.1 Reference modulator diagram

The functional block diagram in Figure 18 is provided as a reference for specifying the 2450 MHz PHY modulation and spreading functions. The number in each block refers to the subclause that describes that function.

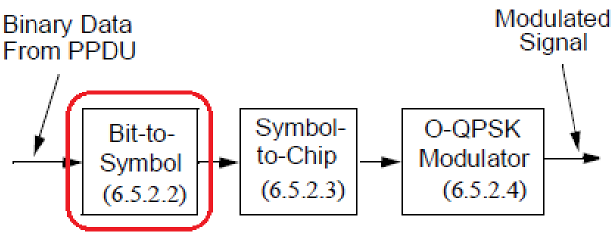


Figure 18—Modulation and spreading functions

https://standards.ieee.org/standard/802_15_4-2003.html

6.5.2.2 Bit-to-symbol mapping

All binary data contained in the PPDU shall be encoded using the modulation and spreading functions shown in Figure 18. This subclause describes how binary information is mapped into data symbols.

The 4 LSBs (b_0, b_1, b_2, b_3) of each octet shall map into one data symbol, and the 4 MSBs (b_4, b_5, b_6, b_7) of each octet shall map into the next data symbol. Each octet of the PPDU is processed through the modulation and spreading functions (see Figure 18) sequentially, beginning with the preamble field and ending with the last octet of the PSDU. Within each octet, the least significant symbol (b_0, b_1, b_2, b_3) is processed first and the most significant symbol (b_4, b_5, b_6, b_7) is processed second.

https://standards.ieee.org/standard/802_15_4-2003.html

As shown below, the data PPDU is an interleaved data, since it is formed by appending Frame Check Sequence to "Data Payload" followed by suffixing "MHR" field to "Data Payload". In as much as successive Data Payloads will be in between them "Frame Check Sequence" of a data payload and "SHR", "PHR" and "MHR", etc., fields of the immediate next data payload, data payloads will be in interleaved form.

IEEE
Std 802.15.4-2003

IEEE STANDARD FOR LOCAL AND METROPOLITAN AREA NETWORKS:

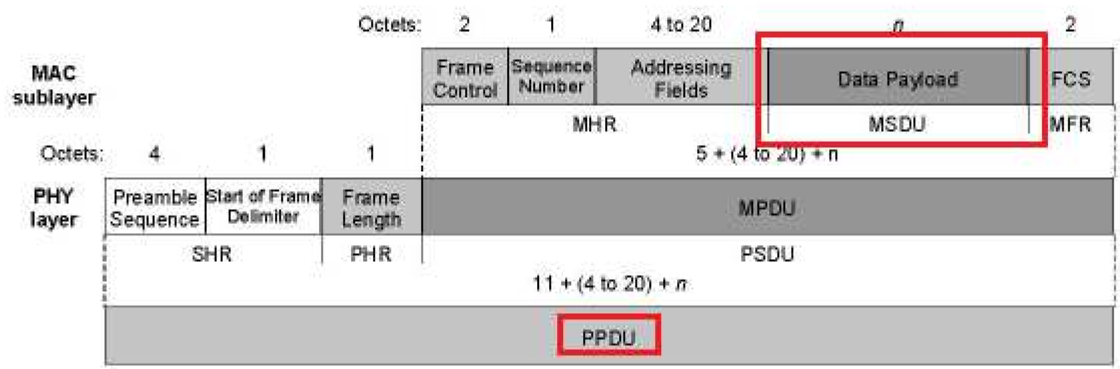
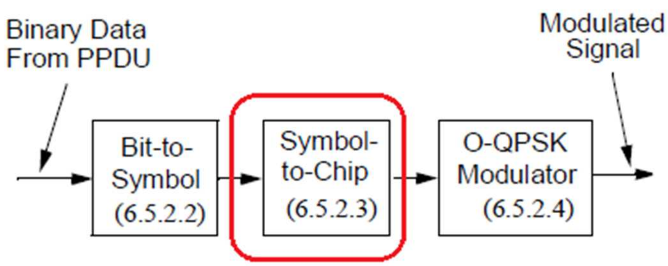


Figure 11—Schematic view of the data frame

The data payload is passed to the MAC sublayer and is referred to as the MSDU. The MSDU is prefixed with an MHR and appended with an MFR. The MHR contains the frame control, sequence number, and addressing information fields. The MFR is composed of a 16 bit FCS. The MHR, MSDU, and MFR together form the MAC data frame, (i.e., MPDU).

The MPDU is passed to the PHY as the PHY data frame payload, (i.e., PSDU). The PSDU is prefixed with an SHR, containing the preamble sequence and SFD fields, and a PHR containing the length of the PSDU in octets. The preamble sequence and the data SFD enable the receiver to achieve symbol synchronization. The SHR, PHR, and PSDU together form the PHY data packet, (i.e., PPDU).

https://standards.ieee.org/standard/802_15_4-2003.html

selecting, at said transmitter in response to the N bits of stored data, a chip-sequence signal from a plurality of 2^N chip-sequence signals, as an output chip-sequence signal; and	The spread-spectrum transmitter (e.g., ZigBee transceiver) utilized by the accused product practices selecting, at said transmitter (e.g., ZigBee transceiver) in response to the N (e.g., N=4) bits of stored data, a chip-sequence signal (e.g., one of 16 PN Sequences) from a plurality of 2^N chip-sequence signals (e.g., 16 PN sequences listed in the table-20 as shown below), as an output chip-sequence signal (e.g., the selected PN sequence for a data symbol). IEEE Std 802.15.4-2003 IEEE STANDARD FOR LOCAL AND METROPOLITAN AREA NETWORKS:  **Figure 18—Modulation and spreading functions** https://standards.ieee.org/standard/802_15_4-2003.html **6.5.2 Modulation and spreading** The 2450 MHz PHY employs a 16-ary quasi-orthogonal modulation technique. During each data symbol period, four information bits are used to select one of 16 nearly orthogonal pseudo-random noise (PN) sequences to be transmitted. The PN sequences for successive data symbols are concatenated, and the aggregate chip sequence is modulated onto the carrier using offset quadrature phase-shift keying (O-QPSK). https://standards.ieee.org/standard/802_15_4-2003.html

	6.5.2.3 Symbol-to-chip mapping Each data symbol shall be mapped into a 32-chip PN sequence as specified in Table 20. The PN sequences are related to each other through cyclic shifts and/or conjugation (i.e., inversion of odd-indexed chip values). https://standards.ieee.org/standard/802_15_4-2003.html As shown below, for each symbol, which comprises 4-bits, 1 of 16 PN sequences are selected. Symbol to chip mapper comprises a table which has sixteen 32-bit PN Sequences (chip values) corresponding to each of sixteen 4-bit data symbol.

6.5.2.3 Symbol-to-chip mapping

Each data symbol shall be mapped into a 32-chip PN sequence as specified in Table 20. The PN sequences are related to each other through cyclic shifts and/or conjugation (i.e., inversion of odd-indexed chip values).

Table 20—Symbol-to-chip mapping

Data symbol (decimal)	Data symbol (binary) (b_0, b_1, b_2, b_3)	Chip values $(c_0\ c_1 \ldots c_{30}\ c_{31})$
0	0 0 0 0	1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0
1	1 0 0 0	1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0
2	0 1 0 0	0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0
3	1 1 0 0	0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1
4	0 0 1 0	0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0 0 0 1 1
5	1 0 1 0	0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1 1 1 0 0
6	0 1 1 0	1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1 1 0 0 1
7	1 1 1 0	1 0 0 1 1 1 0 0 0 0 1 1 0 1 0 1 0 0 1 0 0 0 1 0 1 1 1 0 1 1 0 1
8	0 0 0 1	1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1
9	1 0 0 1	1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1
10	0 1 0 1	0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1
11	1 1 0 1	0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0
12	0 0 1 1	0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1 0 1 1 0
13	1 0 1 1	0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0 1 0 0 1

https://standards.ieee.org/standard/802_15_4-2003.html

WIRELESS MAC AND PHY SPECIFICATIONS FOR LR-WANS

IEEE
Std 802.15.4-2003

Table 20—Symbol-to-chip mapping *(continued)*

Data symbol (decimal)	Data symbol (binary) (b_0, b_1, b_2, b_3)	Chip values (c_0 c_1 ... c_{30} c_{31})
14	0 1 1 1	1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0 1 1 0 0
15	1 1 1 1	1 1 0 0 1 0 0 1 0 1 1 0 0 0 0 0 0 1 1 1 0 1 1 1 1 0 1 1 1 0 0 0

https://standards.ieee.org/standard/802_15_4-2003.html

transmitting, at said transmitter, the output chip-sequence signal as a radio wave, at a carrier frequency, over said communications channel, as a spread-spectrum signal.	The spread-spectrum transmitter (e.g., ZigBee transceiver) utilized by the accused product practices transmitting, at said transmitter, the output chip-sequence signal (e.g., the selected PN sequence for a data symbol) as a radio wave (e.g., modulated RF signal), at a carrier frequency (at a carrier frequency of one of 16 carrier frequencies identified by 2.405 MHz, 2.410 MHz, 2.415 MHz, 2.420, 2.425 MHz, 2.430 MHz, 2.435 MHz, 2.440 MHz, 2.445 MHz, 2.450 MHz, 2.455 MHz, 2.460 MHz, 2.465 MHz, 2.470 MHz,2.475 MHz, and 2.480 MHz) , over said communications channel (e.g., wireless channel), as a spread-spectrum signal.

	4.2. Transmit (TX) Path The EM35x TX path produces an O-QPSK-modulated signal using the analog front end and digital baseband. The area- and power-efficient TX architecture uses a two-point modulation scheme to modulate the RF signal generated by the synthesizer. The modulated RF signal is fed to the integrated PA and then out of the EM35x. **4.2.1. TX Baseband** The EM35x TX baseband in the digital domain spreads the 4-bit symbol into its IEEE 802.15.4-2003-defined 32-chip sequence. It also provides the interface for the Ember software to calibrate the TX module to reduce silicon process, temperature, and voltage variations. **4.2.2. TX_ACTIVE and nTX_ACTIVE Signals** For applications requiring an external PA, two signals are provided called TX_ACTIVE and nTX_ACTIVE. These signals are the inverse of each other. They can be used for external PA power management and RF switching logic. In transmit mode the TX baseband drives TX_ACTIVE high, as described in Table 7.5 on page 57. In receive mode the TX_ACTIVE signal is low. TX_ACTIVE is the alternate function of PC5, and nTX_ACTIVE is the alternate function of PC6. See "7. GPIO (General Purpose Input/Output)" on page 50 for details of the alternate GPIO functions. The digital I/O that provide these signals have a 4 mA output sink and source capability. https://www.silabs.com/documents/public/data-sheets/EM35x.pdf

Figure 3.1 shows a detailed block diagram of the EM35x.

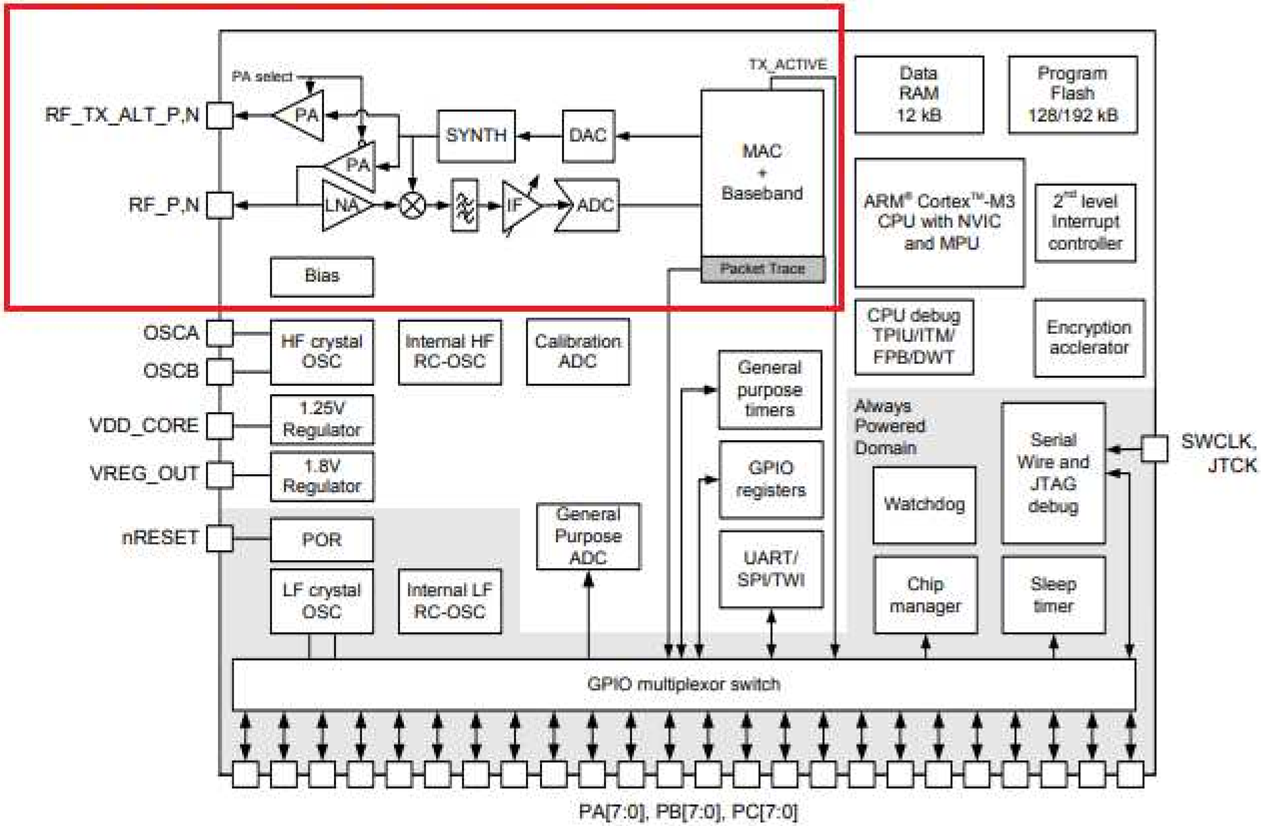


Figure 3.1. EM35x Block Diagram

https://www.silabs.com/documents/public/data-sheets/EM35x.pdf

	Physical and MAC layers The system is specified to operate in one of the three license free bands at 2.4 GHz, 915 MHz for North America and 868 MHz for Europe. In this way the standard is able to operate around the globe, although the exact specifications for each of the bands are slightly different. At 2.4 GHz there are a total of sixteen different channels available, and the maximum data rate is 250 kbps. For 915 MHz there are ten channels and the standard supports a maximum data rate of 40 kbps, while at 868 MHz there is only one channel and this can support data transfer at up to 20 kbps. The modulation techniques also vary according to the band in use. Direct sequence spread spectrum (DSSS) is used in all cases. However for the 868 and 915 MHz bands the actual form of modulation is binary phase shift keying. For the 2.4 GHz band, offset quadrature phase shift keying (O-QPSK) is employed. In view of the fact that systems may operate in heavily congested environments, and in areas where levels of extraneous interference is high, the 802.15.4 specification has incorporated a variety of features to ensure exceedingly reliable operation. These include a quality assessment, receiver energy detection and clear channel assessment. CSMA (Carrier Sense Multiple Access) techniques are used to determine when to transmit, and in this way unnecessary clashes are avoided. As shown below, IEEE 802.15.4, on which ZigBee protocols are built, mandates O-QPSK modulation on various frequency carriers in 2.4 GHz.

6.5.2.4 O-QPSK modulation

The chip sequences representing each data symbol are modulated onto the carrier using O-QPSK with half-sine pulse shaping. Even-indexed chips are modulated onto the in-phase (I) carrier and odd-indexed chips are modulated onto the quadrature-phase (Q) carrier. Because each data symbol is represented by a 32-chip sequence, the chip rate (nominally 2.0 Mchip/s) is 32 times the symbol rate. To form the offset between I-phase and Q-phase chip modulation, the Q-phase chips shall be delayed by T_c with respect to the I-phase chips (see Figure 19), where T_c is the inverse of the chip rate.

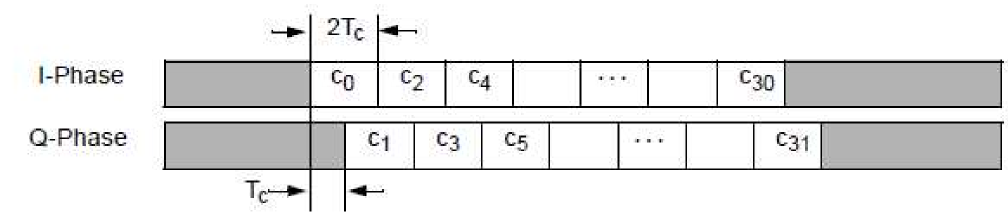


Figure 19—O-QPSK chip offsets

6.5.2.5 Pulse shape

The half-sine pulse shape used to represent each baseband chip is described by Equation (1):

$$p(t) = \begin{cases} \sin\left(\pi \frac{t}{2T_c}\right), 0 \le t \le 2T_c \\ 0, \mathit{otherwise} \end{cases} \quad (1)$$

Figure 20 shows a sample baseband chip sequence with half-sine pulse shaping.

https://standards.ieee.org/standard/802_15_4-2003.html

6.1.2 Channel assignments and numbering

A total of 27 channels, numbered 0 to 26, are available across the three frequency bands. Sixteen channels are available in the 2450 MHz band, 10 in the 915 MHz band, and 1 in the 868 MHz band. The center frequency of these channels is defined as follows:

$$F_c = 868.3 \text{ in megahertz, for } k = 0$$

$$F_c = 906 + 2\,(k - 1) \text{ in megahertz, for } k = 1, 2, ..., 10$$

and $$F_c = 2405 + 5\,(k - 11) \text{ in megahertz, for } k = 11, 12, ..., 26$$

where

k is the channel number.

https://standards.ieee.org/standard/802_15_4-2003.html

IEEE
Std 802.15.4-2003 IEEE STANDARD FOR LOCAL AND METROPOLITAN AREA NETWORKS:

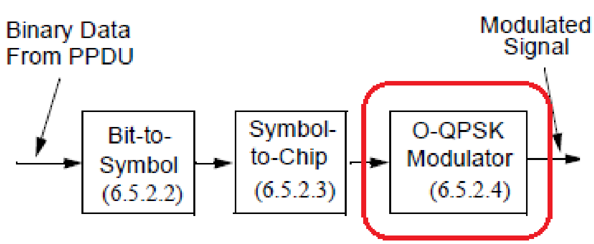


Figure 18—Modulation and spreading functions

https://standards.ieee.org/standard/802_15_4-2003.html

6.5.2.4 O-QPSK modulation

The chip sequences representing each data symbol are modulated onto the carrier using O-QPSK with half-sine pulse shaping. Even-indexed chips are modulated onto the in-phase (I) carrier and odd-indexed chips are modulated onto the quadrature-phase (Q) carrier. Because each data symbol is represented by a 32-chip sequence, the chip rate (nominally 2.0 Mchip/s) is 32 times the symbol rate. To form the offset between I-phase and Q-phase chip modulation, the Q-phase chips shall be delayed by T_c with respect to the I-phase chips (see Figure 19), where T_c is the inverse of the chip rate.

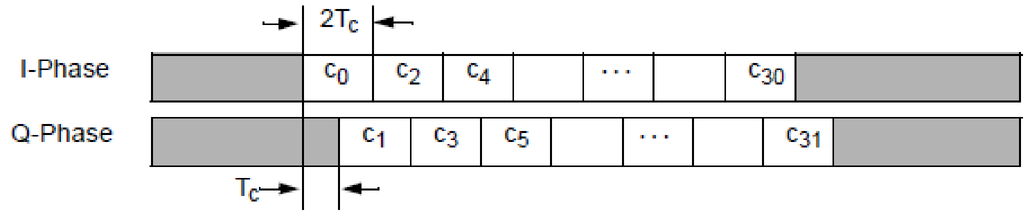


Figure 19—O-QPSK chip offsets

6.5.2.5 Pulse shape

The half-sine pulse shape used to represent each baseband chip is described by Equation (1):

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Figure 20 shows a sample baseband chip sequence with half-sine pulse shaping.

https://standards.ieee.org/standard/802_15_4-2003.html